Design and development of an instream hydrokinetic generator based on oscillating foils

Shreyas Mandre

Brown University

BROWN

arpa·e

Resource potential

River Resource potential

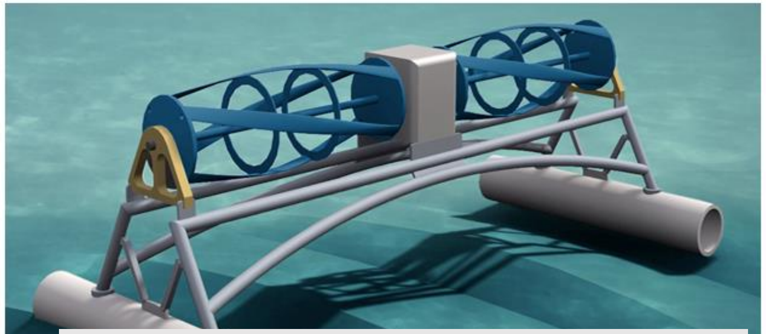
Theoretical: 1381 TW hr/yr (157 GW)
Recoverable: 119 TW hr/yr (13 GW)

Hydrologic region	Recoverable
Lower Mississippi	57.4 TW hr/yr
Alaska	20.5
Pacific Northwest	11.0

(EPRI. Tech. rep. 1026880. 2012)

River instream hydrokinetic resource distribution

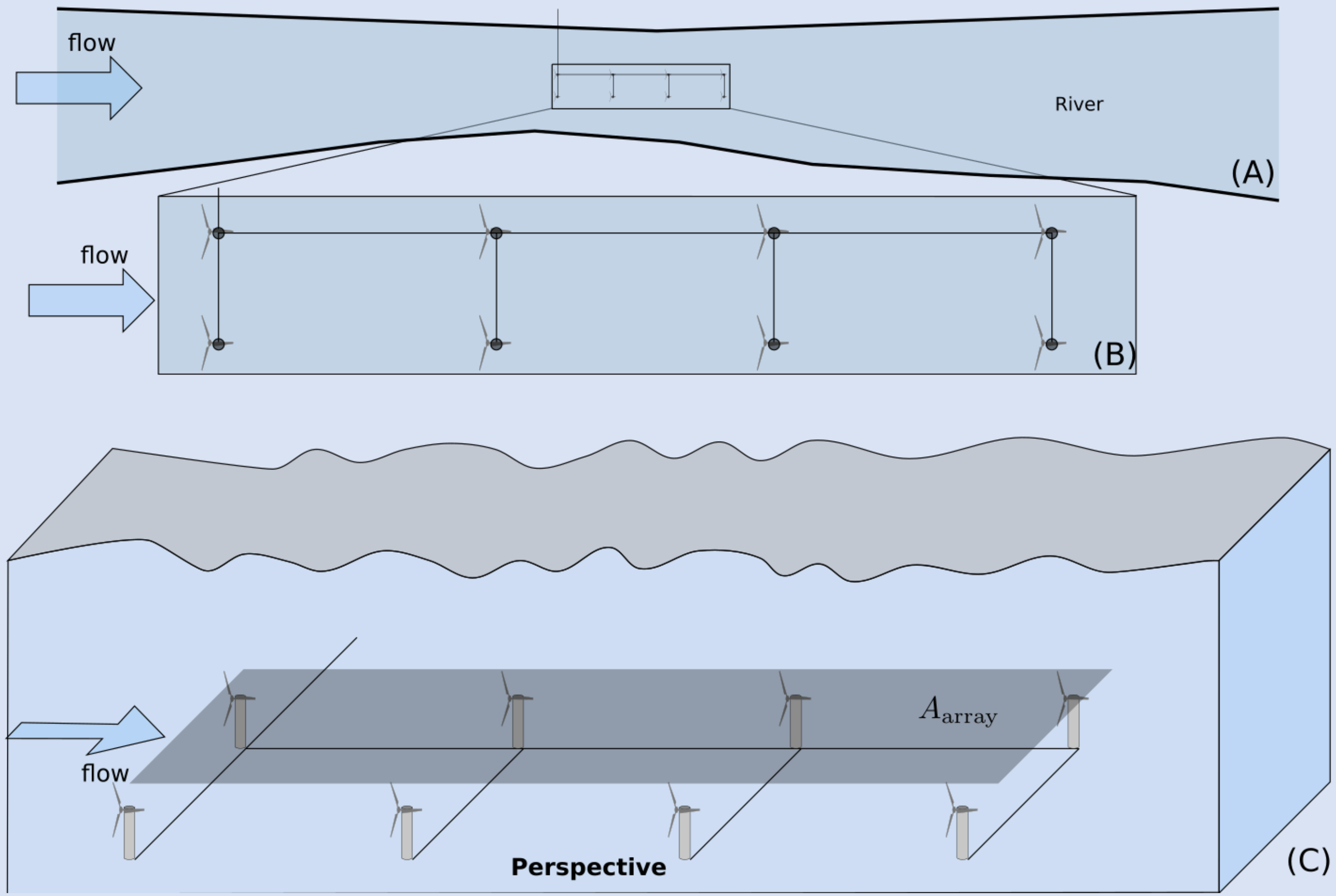
Technology



ORPC Rivgen – cross flow turbine
Image: ORPC

Verdant – axial flow turbine
Image: Verdant

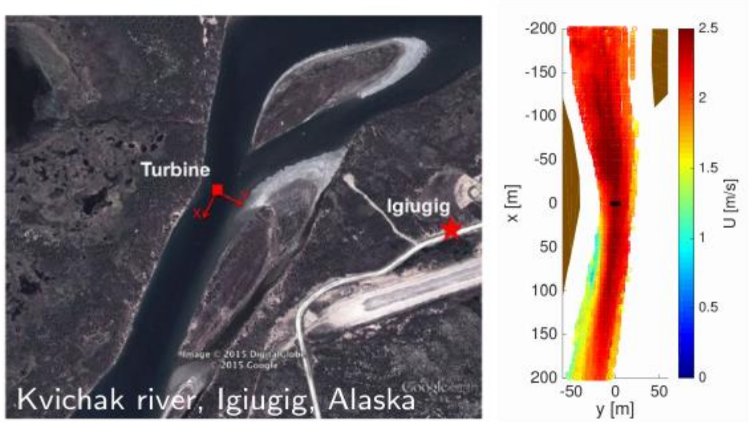
Schematic of an array



The challenge

Hot spots of fast flow

Maricarmen and Thomson, 2016



Navigation image: US Department of Agriculture

Aquatic life: image: US Army Corp of Engineers

Cost of energy image: Verdant Power

Summary:

1. Space
2. Environment
3. Cost

Leading Edge @ Brown


Shreyas Mandre


Michael Miller


Alice Lux Fawzi


Kenny Breuer


Yunxing Suo


Jen Franck

Brown University, School of Engineering


Tom Derecktor


Steve Winckler

BluSource Energy

Engineering

Environment

Commercialization


Erika Sudderth


Kristin Lewis

Volpe Center DOT


Dave Ellerby

Wellesley College


Thorne Sparkman

Slater Tech funds


Brian Demers

Brown TVO


Gus Simiao

Entrepreneur


Chris Atkinson


Bryan Willson


Geoff Short

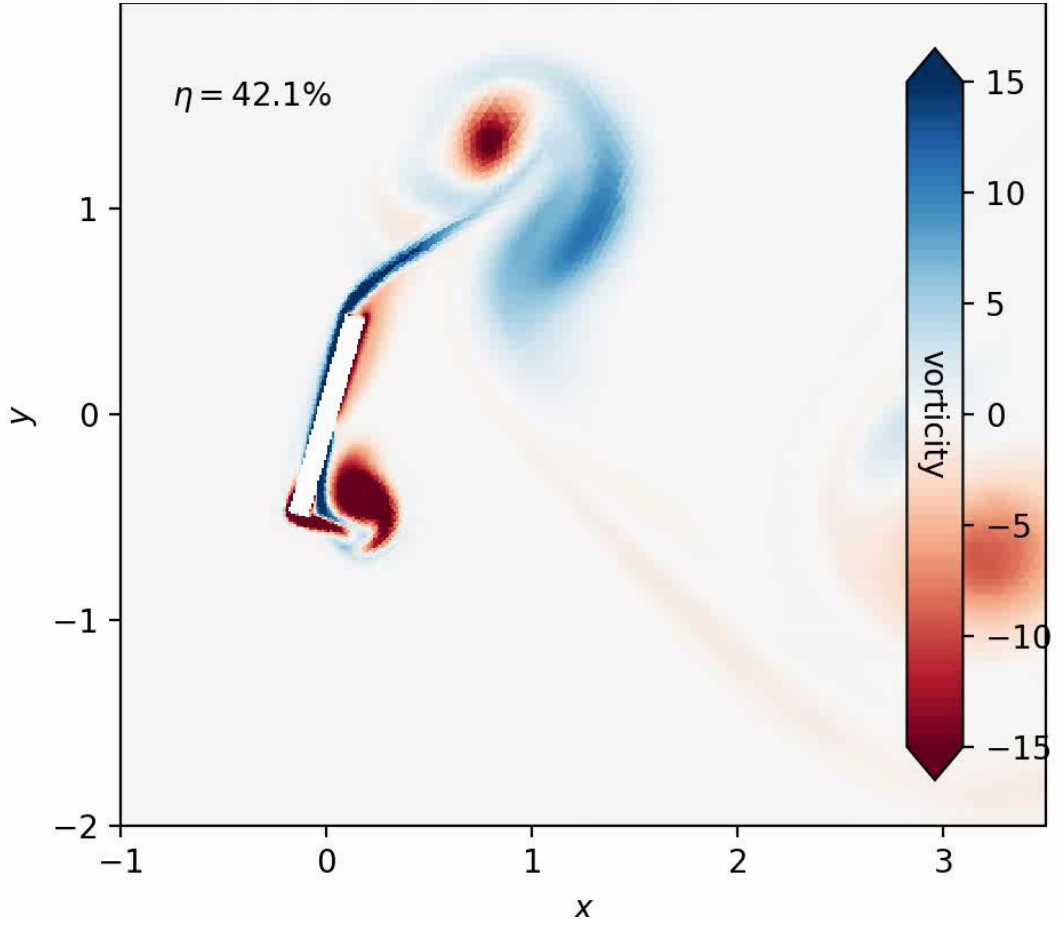

John Tuttle

Advanced Research Projects Agency - Energy

Principle underlying oscillating foils

Basic principle:

1. Pitch in the direction of heaving motion,
2. Large angles of attack – dynamic stall,
3. Leading edge vortex (LEV) enhances lift relative to stalled conditions,
4. Reverse just as the LEV sheds and stall sets in.



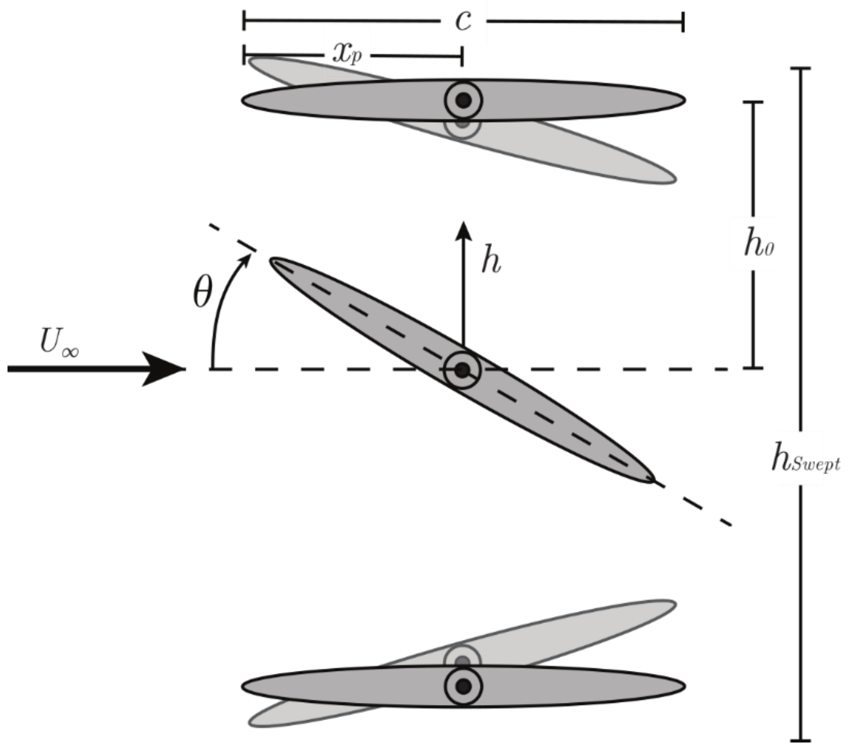
Challenges and opportunities:

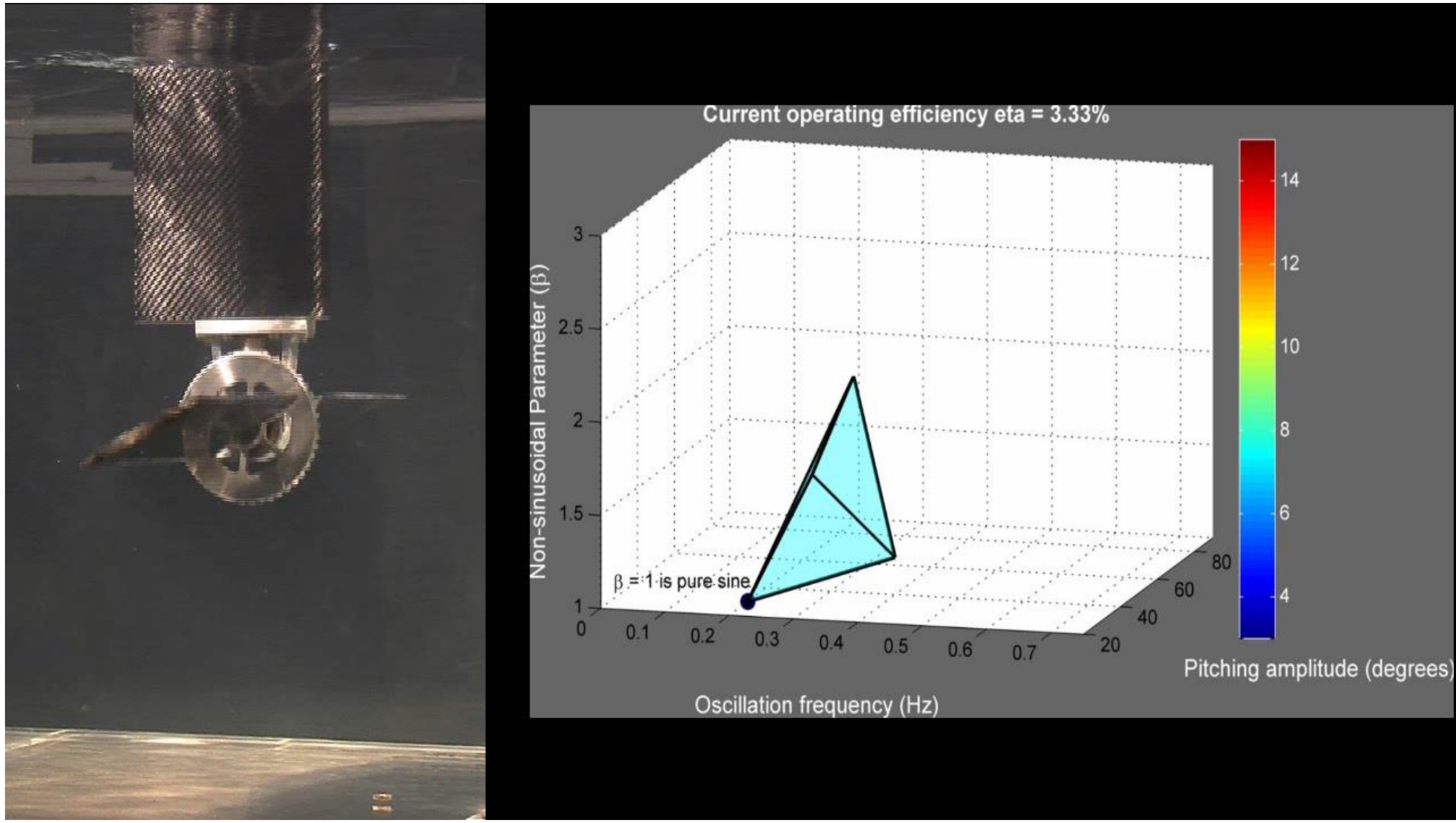
1. Determine the precise motion of the hydrofoil that converts most power,
2. Subject to constraints imposed by the environment, and
3. Adapt to varying conditions.

Opportunity for using runtime optimization.

Proof of concept (Brown University)

Lab scale - version 1.0





$h(t)$ = heaving kinematics
$\theta(t)$ = pitching kinematics

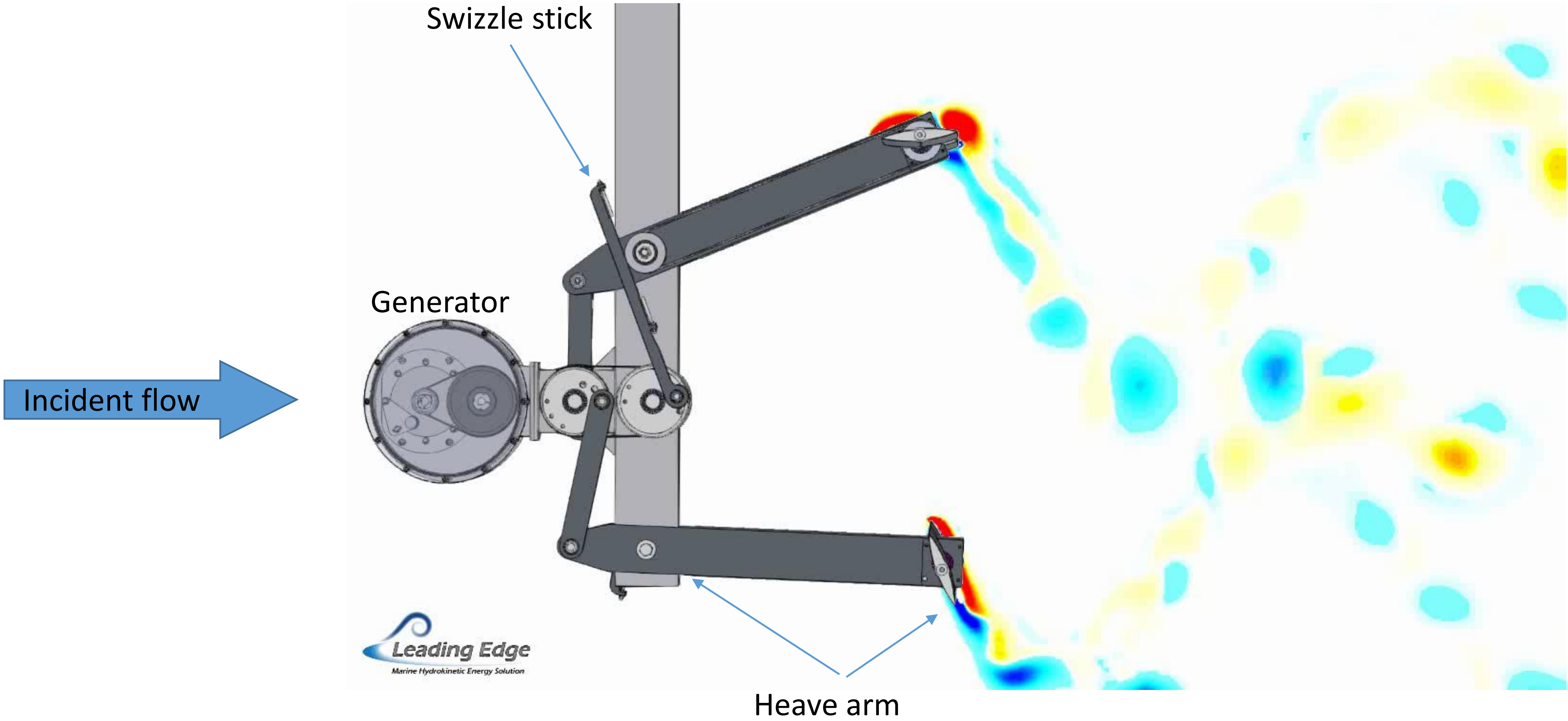
$$Efficiency = \frac{Power\ generated}{Power\ incident\ on\ swept\ area}$$

Lab scale – subsequent versions

Maximum efficiency = 42% !

(Miller, Breuer, Mandre, Optimum pitching-heaving of a foil for extracting power from an incident freestream, *sub judice*, 2018.)

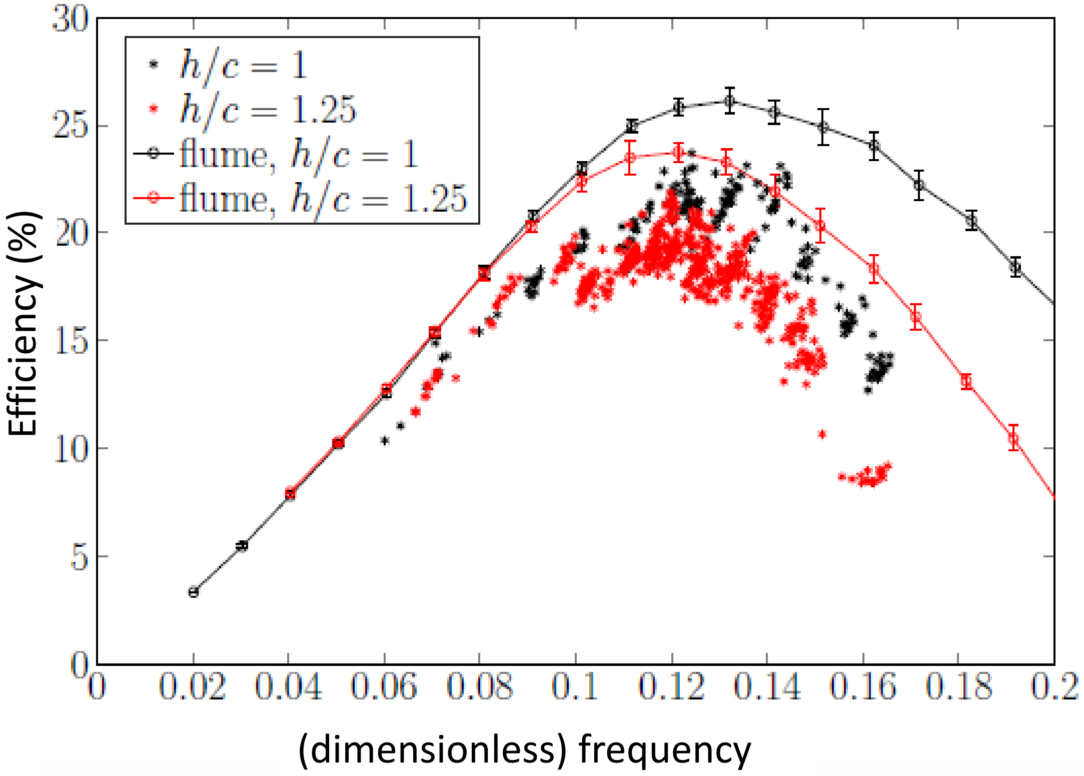
Translation to field technology (BluSource Energy)



Field tests “Orca” – Summer 2015

Mounted on a floating platform:

1. Catamaran configuration
2. Swiveling driven by a winch to retract the foils for maintenance.



Results:

1. Maximum efficiency of 22%.
2. Demonstrate runtime optimization (of oscillation frequency).
3. Agreement with lab experiments for the same foil kinematics.

Techno-economic analysis

Number of generators per pontoon	1	2	3	4
Levelized cost of electricity (projected)	45 c/kWh	36 c/kWh	35 c/kWh	38 c/kWh

Basic idea:

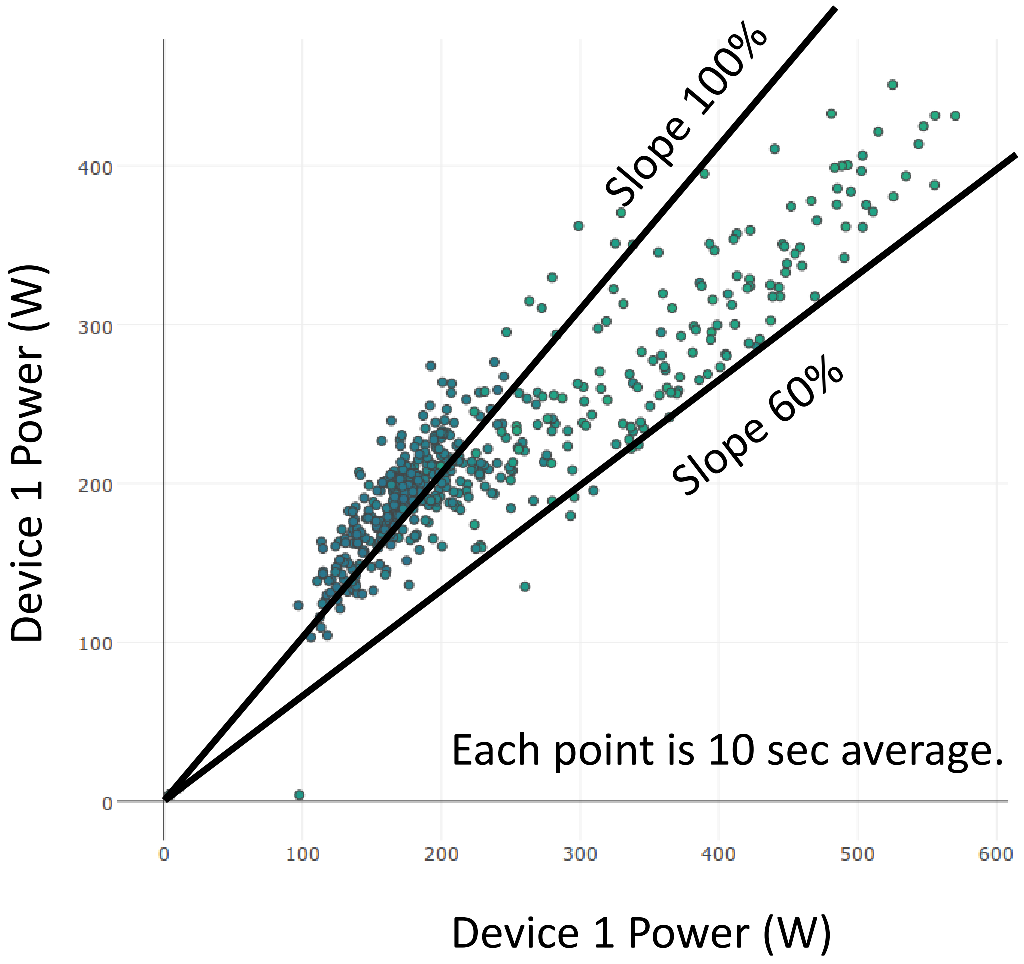
1. Share the cost of the floating platform over multiple generators.
2. But lose power because of hydrodynamic interaction between hydrofoils.
3. Use runtime optimization for minimizing interaction losses.

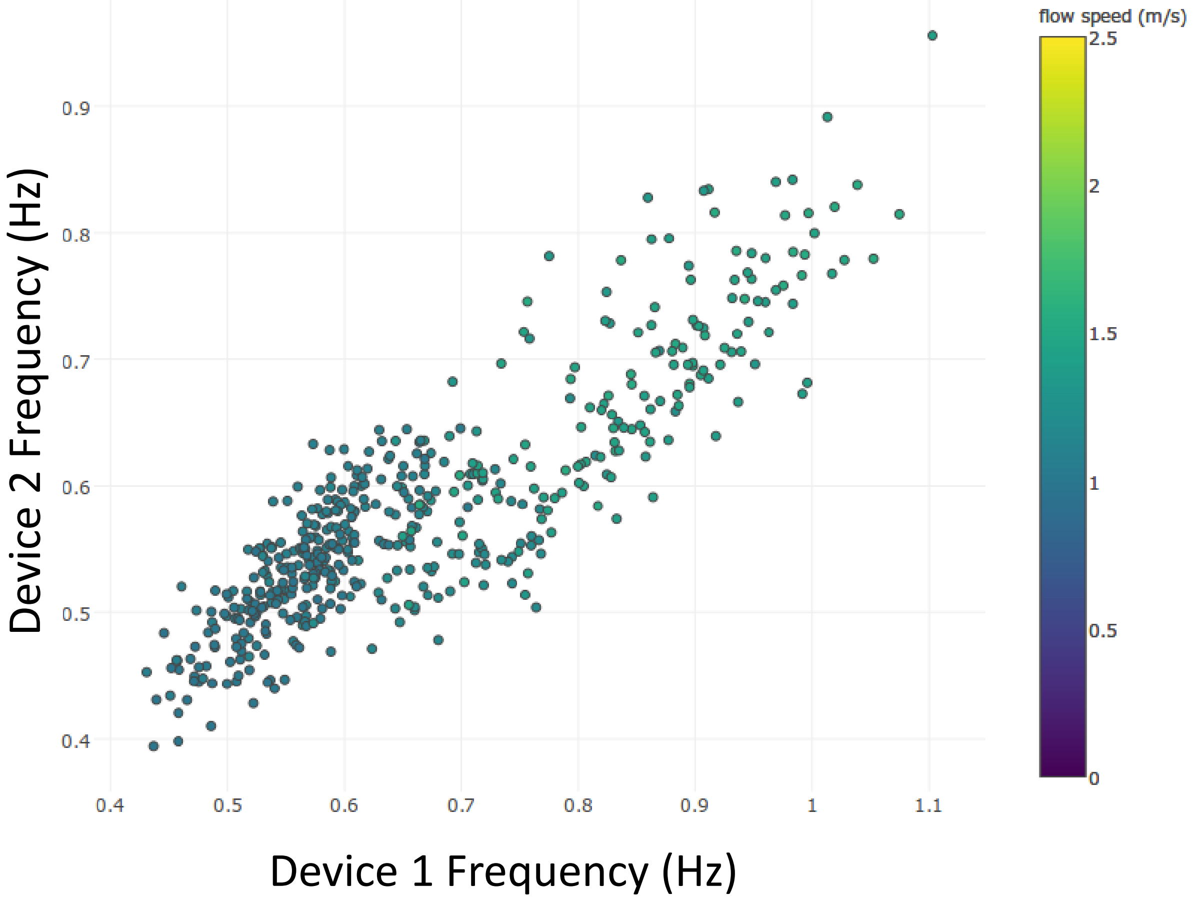
Field tests “Joule” – Summer 2016

Field tests “Joule” – Summer 2016

Field tests “Joule” – Summer 2016

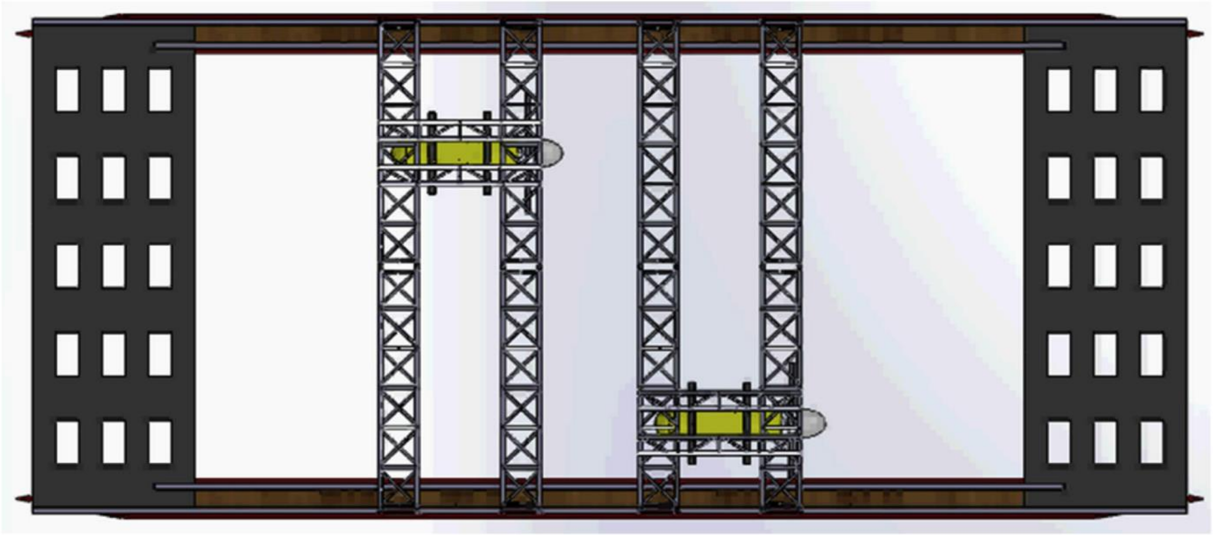
“Joule” performance





- Separation between devices 1.5 – 2 hydrofoil spans.
- Each device runs independent optimization of frequency.
- Trailing device (Device 2) generates > 60% of the leading device.

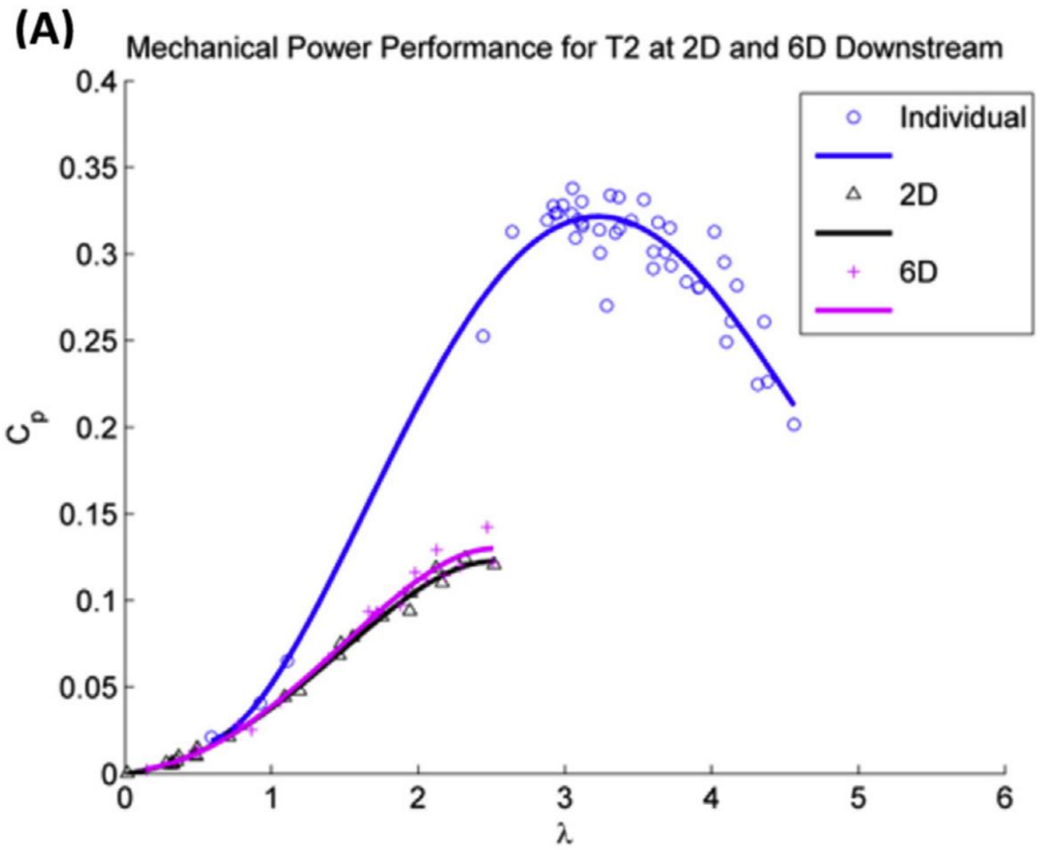
Comparison with axial-flow turbines



Turbine T1 Turbine T2

Reference: Jeffcoate, Whittaker, Boake and Elsaesser. Field tests of multiple 1/10 scale tidal turbines in steady flows. *Renewable Energy* **87** (2016) 240-252.

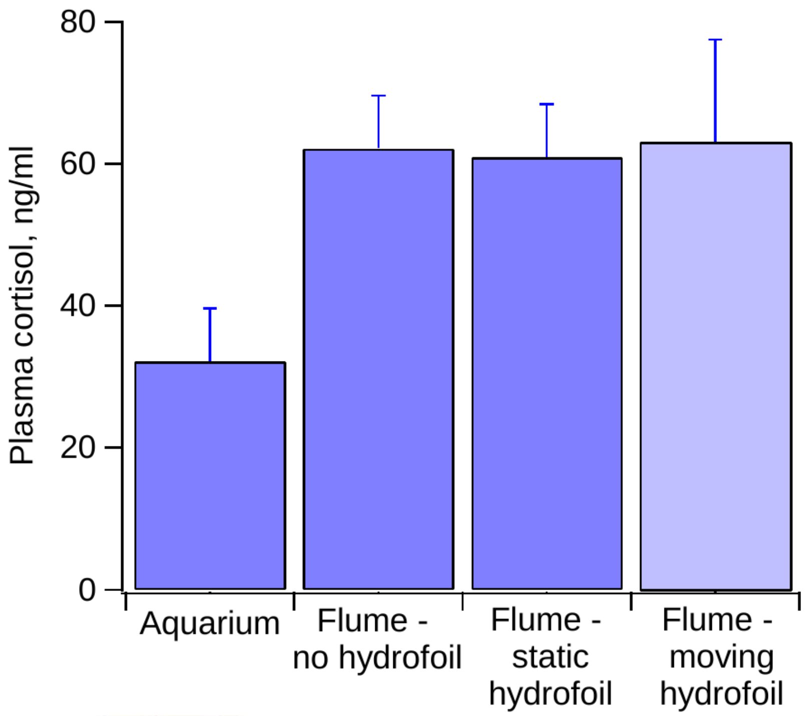
Performance of T2 when placed behind T1



T2 generates at most 30% of the power of an isolated turbine.

Fish friendly

Bluegill sunfish in the flume

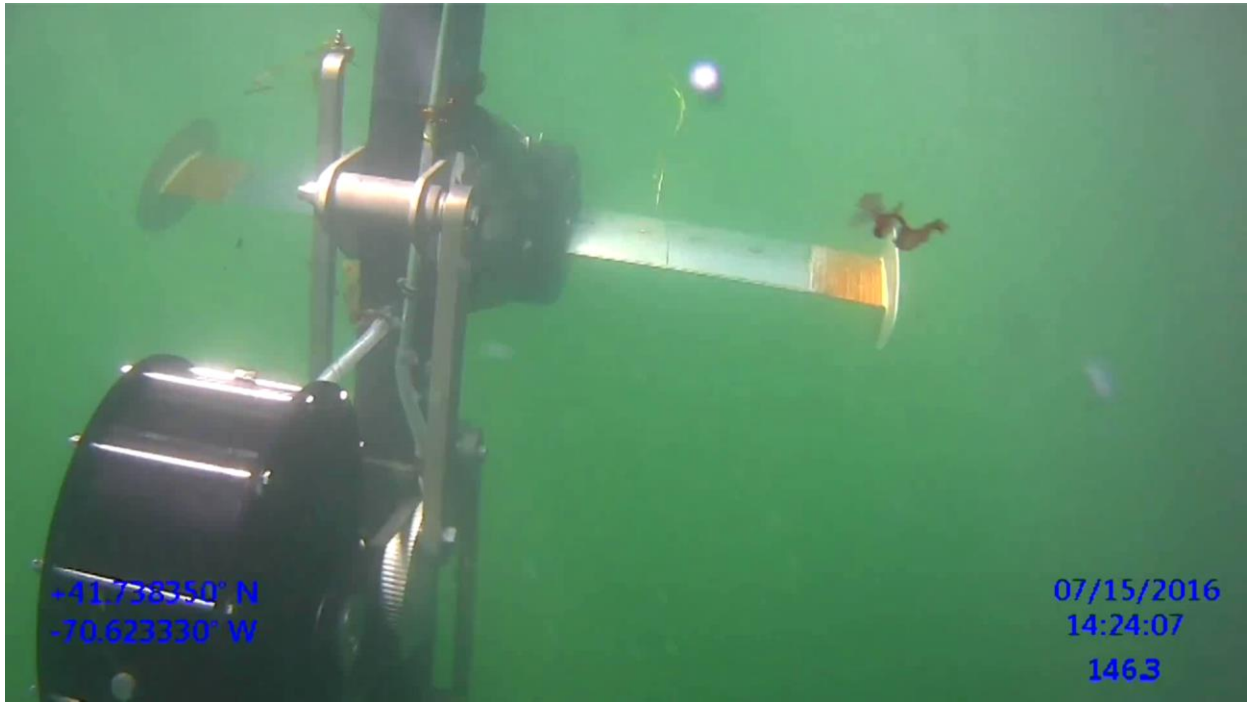


- Maximum speed of the optimum kinematics is equal to freestream.
- Fish capable of navigating around the foils.

Prof. Dave Ellerby,
Wellesley College

Conclusion

1. Oscillating foils for instream hydrokinetic energy conversion.
2. Maximum efficiency:
   - Lab (hydrodynamic): 42%
   - Field (water-to-wire): 22%
3. Runtime optimization effective for:
   - selecting between different kinematics,
   - Minimizing hydrodynamic interference between neighboring devices.
4. Slow motion makes oscillating foils friendly to marine life.



Future work:

Use the idea of runtime optimization of oscillating foils for propulsion.

Thank you for your attention!